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EUROPEAN PATENT APPLICATION

(12)

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(54) Method of inspecting the array of balls of an integrated circuit module.

(57) Method of inspecting an array of balls (10) used as connections in integrated circuit modules such as Solder Ball Connection modules, by means of an inspection machine comprising a microprocessor (34) controlling a vertical camera (38) and an tilted camera (40) for obtaining images of the balls, comprising the steps of measuring the coordinates X and Y of each ball of the array of balls in order to determine a best fitting grid of the balls, detecting the coordinate Z of each ball in order to determine a best fitting plane for the array of balls, offsetting the best fitting plane so that the offset plane includes the lower ball of the array of balls, computing the deviation between each ball and the offset plane, and comparing the computed deviations with predetermined specifications to determine whether the inspected module is in compliance with the specifications.
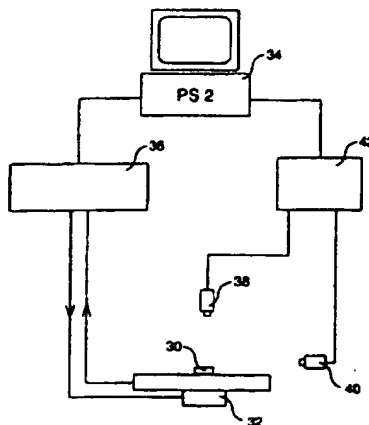
FIG. 4

EP 0 638 801 A1

The invention relates to the inspection methods used in the manufacturing of integrated circuit modules, and relates particularly to a method of inspecting the array of balls used for outside connections in an integrated circuit module in order to determine if the inspected module meets the manufacturing specifications.

5   In many integrated circuit modules and in particular SBC (Solder Ball Connection) modules, balls replace the conventional connection pins. The substrate generally includes a plurality of circuitry layers which connect the chips together and to the balls utilized as inputs/outputs. Then, such modules are soldered on printed circuit board by means of a matrix of conductive pads.

    The overall reliability of the bonds created by the soldered ball process is adversely affected by
10 defective balls. For example, if a ball has an insufficient height, then no electrical connection is made between the ball and the corresponding pad of the circuit board.

    In the past, there have been proposed various kinds of bonding inspection machines. Thus, US patent 4,688,939 describes an inspection machine of solder bumps by placing the chip carrier on a platform beneath a ring light which is in registration with a television camera. Light which is directed at an angle
15 towards all sides of the chip carrier is only reflected upwardly into the camera by the solder bumps. The output signal of the camera which varies with the intensity of the light reflected from the bumps, is processed by a vision system to obtain a one-dimensional intensity plot of the light intensity. The one-dimensional plot is analysed automatically by the system to detect for missing or excessive solder bumps on the chip carrier.

20   Likewise, US patent 5,058,178 relates to an apparatus wherein defective or missing solder bumps of a chip carrier are detected by first illuminating the carrier with dark field illumination. Next, the image of the surface is captured by a television camera. The captured image is processed to detect defects by first creating a window in the image about each group of solder bumps and then creating a bounding box about each bump in each window. Each of a set of attributes including the number, size and location of the
25 windows, the size location and number of boxes in each window, and the dimensions shape and brightness of the image in each box, is measured. The value of each attribute is compared to a reference value representing the value of the attribute when no defects are present. If the attribute differs by more than a predetermined tolerance for its reference value, this is indicative of a particular defect.

    Inspection machines implemented until now have been used to check each solder bump and verify
30 whether the bump meets some requirements so that it can be considered as having a defect or not. But now none of these machines inspects the whole array of bumps or balls to determine whether the bumps or balls are correctly located with respect to other bumps or balls of the array.

    The object of the invention is therefore to provide an automatic method of inspecting an array of balls used for outside connections in an integrated circuit module in order to determine whether the module is
35 acceptable for manufacturing conditions.

    Another object of the invention is to provide an automatic method of inspecting the centrality and the flatness of an array of balls used for outside connections in an integrated circuit module.

    Still another object of the invention is to provide an automatic method of inspecting an array of balls used for outside connections in an integrated circuit module by checking the alignment and the flatness of
40 the balls between them without utilising an absolute reference like the edge of the substrate.

    Accordingly, the present invention relates to a method of inspecting an array of balls used as connections in integrated circuit modules such as Solder Ball Connection modules, by means of an inspection machine comprising a microprocessor, a light source, a table on which is placed the module to be inspected, the coordinates of the table being controlled by the microprocessor, and at least one camera
45 connected to the microprocessor for obtaining images of the balls lighted by the light source. The method consists in measuring the coordinates X and Y of each ball of the array of balls in order to determine a best fitting grid of the balls, detecting the coordinate Z of each ball in order to determine a best fitting plan for the array of balls, offsetting the best fitting plan so that the offset plan includes the lower ball of the array of balls, computing the deviation between each ball of the array of balls and the offset plan, and comparing the
50 computed deviations with predetermined specifications to determine whether the module is in compliance with the specifications.

    This object and further objects, features and advantages of the subject invention will become more evident with the following description read in connection with the accompanying drawings wherein:

    Figure 1 discloses a module of the type Solder Ball Connection module used in the inspection method
55 according to the invention,

    Figure 2 shows a cross-section of a ball soldered to the pad of the module substrate,

    Figure 3 is a schema of the module soldered by balls to a printed circuit card,

    Figure 4 is a bloc diagram of the system used in the inspection method according to the invention,

Figure 5 represents three examples of ball arrays which can be inspected during the inspection method according to the invention,

Figure 6 discloses the way the successive views of groups of balls are recorded in the method used to determine the centrality of the array of balls,

Figure 7 represents three diagrams showing the deviations to be taken into account when the height of the balls is determined,

Figure 8 discloses schematically the system used to determine the flatness of the array of balls in the inspection method according to the invention,

Figure 9 is a photograph showing the view of the lighted balls during the method according to the invention,

Figure 10 is a schema illustrating the correction to be brought in the height determination when the ball is not at its theoretical position,

Figure 11 illustrates schematically the misalignment between the camera and the table carrying the module to be inspected,

Figure 12 represents a pair of juxtaposed views including a drift between the first and the second views,

Figure 13 represents a pair of juxtaposed views separated by a gap due to the scale problem,

Figure 14 illustrates schematically the deviation between the image plan and the vertical plan in the determination of the Z scale, and

Figure 15 discloses schematically the light ring used as light source in the inspection method according to the invention.

The module to be inspected is generally of the type Solder Ball Connection (SBC) module shown in Figure 1. For this kind of module, the balls 10 replace the conventional pins used to achieve the connections. Substrate 14 contains a plurality of circuitry layers which connect chips 12 together and to the balls used as input/output connections. The chips are enclosed by a cap 16 for each module. As shown in Figure 2, each ball 10 is connected to a pad 18 of substrate 14 by a point of solder 20.

Several modules are then soldered on a printed circuit card by soldering the balls on the receiving pads 22 of the card 24 as shown in Figure 3. If the array of balls soldered on the module is not plane, some balls 10 may be too far from the pad 22 to be soldered thereto, and finally, the connection is not achieved with the card. Also, if the matrix of balls is not regular, some balls may not be facing the corresponding pads, and again the connection will not be achieved because the balls will not be soldered to their pads.

METHOD OF INSPECTION

The method of inspection according to the present invention enables the array of balls to be inspected with high accuracy and high speed. Such a method is accomplished by means of an inspection machine illustrated in Figure 4. A module 30 is positioned on a motorised table which is movable according to axis X and axis Y. The motion of table 32 is controlled by microprocessor 34 (which can be, for example, an IBM PS/2), via the control unit 36. The table can be moved so that the coordinates X and Y of the modules can be adjusted very precisely.

To perform the inspection of the ball positions in the plane coordinates X, Y as well as for the height with respect to the horizontal plane, two cameras 38 and 40 are used. As will be described hereafter, camera 38 is used to measure the centrality of the ball array, and camera 40 is used to sense the flatness of the array. The two cameras 38 and 40 are connected to a controller 42 which is itself connected to microprocessor 34. Controller 42 processes the vision algorithms, computes the results, adjusts the light intensity, and selects the camera, whereas microprocessor 34 performs all controls, synchronises the axes motion with the vision process and is used to interface with the operator.

The first step of the inspection method according to the invention consists in checking the regularity of the ball array or measuring the centrality of the array. The principle is not to sense the position of each ball with respect to an absolute reference like the edge of the substrate, but to define the position of each ball in the array of balls regarding the other balls of the array. Thus, three modules are illustrated in Fig 5. The first module A has its array of balls which forms an irregular matrix. Such a module will be discarded. Conversely, module B which has a shifted matrix of balls, and module C which has a turned matrix of balls, can be kept because, in both cases, the matrix of balls is regular.

Practically, the step consists in measuring accurately the position of each ball, computing a best fitting grid which is a theoretical grid matching at best all the balls, and finally computing the deviation between each ball and its theoretical position in the best fitting grid. Such a measure is achieved by means of the vertical camera 38 (see Fig 4) which takes successive views of the array of balls in the manner illustrated in Fig. 6 showing the module 30 in grey. Each view 1, 2, 3, ... 6, 7 can correspond to a matrix of m x n balls.

3

Thus, one view can take the image of 20 balls corresponding to a matrix of 4 x 5. The parameters m and n are determined by the distance of which the table carrying the module is moved each time a view has to be taken. It must be noted that the way the views are taken, sometimes called "Boustrophedon", results in the scanning of the whole module in a minimum time.

5   After all the views have been taken, they have to be combined in order to build the image of the module. This raises some problems due to the misalignment of the camera with respect to the table. Such problems resulting from the image "drift" are solved by the calibration step which will be described later.

The image magnification and the scale depend on the distance object/camera. Thus, if the distance grows, the magnification becomes small. The specifications on the thickness of the module are large, for

10 instance 0,9 mm. But the scales are false for a difference as small as 0,1 mm. From a cycle point of view, it is not possible to calibrate the tool for each module. So, the distance module/camera must be adapted to the memorised scales for each module. The machine inspection uses two cameras with different view angles resulting in the ability to process stereo-vision in order to determine any height variation. Two different views are processed from the same object and a 3D information is computed. This information is

15 compared with an information memorised during the calibration step described hereafter, and Z axis is automatically adjusted to have a constant height between the camera and the module. Such a method enables to determine a 10μ deviation.

As illustrated in Figure 7, the height difference for each module is determined easily by means of the two cameras. In diagram A, there is no height difference and no adjustment is necessary. In diagram B, the

20 height difference Dh is determined by measuring the deviation D1 measured by the flatness (tilted) camera.

$$Dh = \frac{D1}{\cos\varphi}$$

25

In diagram C, further to the difference in height, there is also a difference in position detected as D2 by the vertical camera. In such a case, the height difference is:

30

$$Dh = \frac{D1 + D2.\sin\varphi}{\cos\varphi}$$

35

When the height difference has been accurately determined by measuring it for several balls and taking the average, the vertical camera is moved of the distance Dh before processing further.

Then, the height of the balls is determined by taking a view for each group of 4 balls. As shown on figure 8, a light source 50 is located opposite camera 40. In order to obtain a diffused light, a diffuser 52 is

40 disposed between light source 50 and the balls 10. With such a light system it is very easy for the camera to take a view of the light reflection 54 at the top of the balls as illustrated in figure 9 by the four crosses represented on the top of the 4 balls.

For each ball, a correction of the height is necessary because ball 10 is not at its theoretical position 58 as shown in figure 10. Such a deviation with respect to the theoretical Y coordinate is known by measuring

45 the alignment of the balls and determining the theoretical grid as already described. With the angle of the camera being Y, the correction value to be applied to the view is

$$D = L \sin \phi$$

50 with L being the deviation of the ball with respect to its theoretical position.

Then, the table is moved to take a view of the next four balls. The way of taking the views of the balls (Boustrophedon) is the same as the way the views are taken for measuring the alignment of the balls.

After the heights of the balls forming the array of balls have been determined, corrected and stored, a plane fitting at most the top of the balls, called hereafter the "best fitting plane" is computed using the

55 Least Square Regression method.

If $X(i,j)$; $Y(i,j)$; $Z(i,j)$

are the coordinates for each ball top, the equation for a plane including such a point is

4

$$Z_{plane} = a.X(i,j) + b.Y(i,j) + c$$

The squared distance between any object and the plane is

5    $E(i,j) = [Z_{plane} - Z(i,j)]^2$

The process consists in computing 3 parameters of the plane which minimize the sum of the squared distances

10    $D = \text{sum } E(i,j)$

D is then derived with respect to the three unknown coefficients a, b, c, and the derivatives are made to zero.

    Let us define

15

$$S = Z_{plane} - Z(i,j)$$
$$S = a.X(i,j) + b.Y(i,j) + c - Z(i,j)$$

Therefore,

20

$$dE(i,j)/d^* = 2.dS/d^*.S$$

where * stands for any of a, b, c.

25    $dE(i,j)/da = 2.X(i,j).[a.X(i,j) + b.Y(i,j) + c - Z(i,j)]$
         $dE(i,j)/db = 2.Y(i,j).[a.X(i,j) + b.Y(i,j) + c - Z(i,j)]$
         $dE(i,j)/dc = 2.[a.X(i,j) + b.Y(i,j) + c - Z(i,j)]$

These expressions are summed over the working set and the results are equated to zero.

30

S1 = sum X	S4 = sum X^2	S6 = sum X.Y
S2 = sum Y	S5 = sum Y^2	S7 = -sum X.Z
S3 = -sum Z		S8 = -sum Y.Z

35

    This gives (n being the number of objects in the working set

    $0 = a.S4 + b.S6 + c.S1 + S7$ (1)

40    $0 = a.S6 + b.S5 + c.S2 + S8$ (2)

    $0 = a.S1 + b.S2 + c.n + S3$ (3)

    Let us have

45

    (1).S6 - (2).S4   (4)
    $0 = b.(S6.S6-S5.S4) + c.(S1.S6-S2.S4) + (S7.S6-S4.S8)$

    (2).S1 - (3).S6   (5)
50    $0 = b.(S5.S1-S2.S6) + c.(S1.S2-n.S6) + (S8.S1-S3.S6)$

    Let us define
        A = (S6.S6-S5.S4) C = (S7.S6-S4.S8) E = (S1.S2-n.S6)
        B = (S1.S6-S2.S4) D = (S5.S1-S2.S6) F = (S8.S1-S3.S6)
55 Equations (4) and (5) become

    $0 = b.A + c.B + C$
    $0 = b.D + c.E + F$

5

Let us have

(4).E - (5).B

5   $0 = b.(A.E - D.B) + (C.E - F.B)$

This gives coefficient b

$b = -(C.E - F.B)/(A.E - D.B)$

10

Then it is easy to get a and c

$a = -(b.S6 + c.S1 + S7)/S4$
$c = -(B.D - A.E)/(D.C - A.F)$

15

Then, the deviations between the balls of the array and the best fitting plane are computed. The best fitting plane is offset so that the new plane, or inspection plane, includes the top of the lowest ball of the array. Again, the deviations between the balls and the inspection plane are computed. Finally, the computed deviations are compared with the specifications whereby the module is accepted if the deviations meet the 20   specifications or the module is discarded if the deviations do not meet the specifications.

MACHINE CALIBRATION

The machine used for performing the process according to the invention being an alignment tool, the 25   calibration is a particularly important step of the whole process. For a classical vision tool processing on a single image, the calibration phase consists in determining the ratio camera pixel/real size. This ratio is called "scale" and depends on the optical magnification.

Preferably, a CCD (coupled charge device) camera is used. In such a camera, a pixel is not square, so the scale for the two axes X and Y has to be determined. Furthermore, one axis motion being done between 30   two image acquisitions, we have also to take into account the drift resulting on the misalignment between the camera axis and the table axis as shown in Figure 11.

Accordingly, the calibration is achieved in two steps: a coarse calibration and a fine calibration. During the coarse calibration, in order to determine approximately the pixel scale, one image is snapped (20 balls for centrality and 4 balls for flatness), and the average of deviation between the balls is computed by 35   combining them two by two.

The fine calibration gives, with high accuracy, the scales X and Y and the drifts X and Y for the centrality camera which is a vertical (if the X and Y table axes are not perpendicular, drift X is different from drift Y). For the flatness camera which is tilted at an angle of about 15° with respect to the horizontal plane, the calibration gives the scale Z and the reference for Z axis, that is the distance between the module and 40   the vertical camera used for the centrality.

To perform a fine calibration, a complete module is processed by the inspection method according to the invention using the scale resulting from the coarse calibration.

The drift is illustrated in Figure 12 showing two successive views. The slope of the module is computed by averaging all the balls of each view and aver all the views. Such a slope is called "correction" (CORR). 45   The variation from a view to the following view (VARI) is averaged on all the balls located on the image edges.

DRIFT = VARI (x,y) - CORR (x,y)

50   As far as the scale is concerned, such a problem is illustrated in Figure 13 showing two views separated by a gap due to the scale problem. This problem is easily solved by noticing that, if R is the ratio of the value of the distance between the balls of the views, it is also the ratio of the used scale to the real scale. Therefore, once R is computed, it is very easy to rectify the scale. It must be noted that the distances between balls are averaged on the whole module resulting in a high accuracy.

55   For the flatness measurements, it is necessary to determine the Z scale. For this, we need to know the angle θ between the image plane and the vertical plane as illustrated in Figure 14. If RS is the real scale and SS the seen scale, the following equations can be set:

6

RS(X) = SS(X)
RS(Y) = SS(X).R

$$\sin\theta = \frac{SS(Y)}{RS(Y)}$$

$$Scale(Z) = \frac{RS(Y)}{\cos\theta}$$

With reference to Figure 15 it must be noted that, in order to obtain an image including the balls without any shadow which could disturb the measuring process, a non-directed and homogeneous light source called a "light ring" 60 is used to light module 30 during the whole inspection process. Such a light ring composed of 100 LEDs is very advantageous in that it does not provide much heat which would constitute a nuisance for achieving the inspection.

Claims

1. A method of inspecting an array of balls (10) used as connections in integrated circuit modules (30) such as Solder Ball Connection modules, by means of an inspection machine comprising a micropro-cessor (34), at least a light source (50), a table on which is placed the module to be inspected, the coordinates of said table being controlled (32) by said microprocessor, and at least one camera (38, 40) for obtaining images of the balls lit by said light source, said at least one camera being connected to said microprocessor; said method being characterised by the steps of:
measuring the coordinates X and Y of each ball of said array of balls in order to determine a best fitting grid of the balls,
detecting the coordinate Z of each ball in order to determine a best fitting plane for said array of balls, offsetting said best fitting plane so that the offset plane includes the lower ball of said array of balls, computing the deviation between each ball of said array of balls and said offset plane, and comparing the computed deviations with predetermined specifications to determine whether said module is in compliance with said specifications.

2. The method according to claim 1 wherein the step of determining the best fitting grid of the balls consists in:
measuring accurately the position of each ball (10) in said array of balls of each module (30),
computing, from the coordinates of all the balls in said array of balls, a theoretical grid (best fitting grid) which matches all the balls at best, and
computing the deviation between each ball and its theoretical position in said best fitting grid.

3. The method according to claim 2 wherein said step of measuring accurately the position of each ball (10) in said array of balls consists in taking views of successive juxtaposed parts of the array of balls (fig. 6) by means of a vertical camera (38), each part comprising m x n balls.

4. The method according to claim 1 2, or 3 wherein said step of detecting the coordinate Z of the top of each ball (10) In said array of balls consists in taking views of successive juxtaposed rows (fig. 9) of the array of balls by means of an tilted camera (40), with the balls being lit by a light source (50) located opposite said camera with respect to said array of balls so that the image of a ball taken by said camera in each view corresponds to a light reflection at the top of said ball.

5. The method according to claim 4 wherein said step of determining the best fitting plane for said array of balls consists in applying the Least Square Regression method to the computation of the plane parameters which minimizes the sum of the squared distances between it and the balls.

6. The method according to claim 2 and 4 or 5 wherein the coordinate Z of the top of each ball (10) detected by means of said tilted camera (40) is corrected taking into account the deviation of the

position of said ball with respect to its theoretical position (fig. 10) in said best fitting grid.

7. The method according to claim 4, 5 or 6 wherein, before said step of detecting the coordinate Z of the top of each ball (10), the height of each module (30) with respect to said vertical camera (38) is adjusted so as to take the module thickness into account.

8. The method according to any one of the preceding claims wherein a calibration phase including a coarse calibration followed by a fine calibration is performed prior to any inspection process applied to modules, so as to determine the scale and the drift to take into account during the inspection phase.

9. The method according to claim 8 wherein said coarse calibration consists in snapping an image of an array of balls and computing the average of deviation between balls by combining them two by two in order to determine approximately the pixel scale.

10. The method according to claim 8 or 9 wherein the phase of fine calibration is performed by applying to a module the steps of the inspection method using the scale resulting from said coarse calibration; said fine calibration consisting in:

determining the drift resulting from the misalignment between the camera axis and the table axis by computing the difference between the value of the variation from a view to the adjacent view taken by a vertical camera (38) and the slope of the module with respect to the supporting table,

determining the X and Y scales by computing the ratio of the value of the distance between the balls of a view to a value of the distance between the balls of two views, said views being taken by said vertical camera, and

determining the Z scale by using the angle θ between the vertical plan and the image plan when a view is taken with an tilted camera (40).

11. An inspection machine for inspecting an array of balls (20) used as connections in integrated circuit modules (30) such as Solder Ball Connection modules, using the method according to any one of the preceding claims, said inspection machine being characterized in that it comprises:

a microprocessor (34),

at least a light source (50),

a table on which is placed the module (30) to be inspected , the coordinates of said table being controlled by said microprocessor,

a vertical camera (38) mainly used to determine the centrality of said array of balls,

an tilted camera mainly used to determine the flatness of said array of balls, and

a controller (42) interconnected between said microprocessor (34) and said vertical and tilted cameras for processing the vision algorithms and transferring the results to said microprocessor.

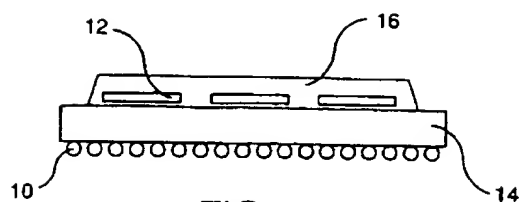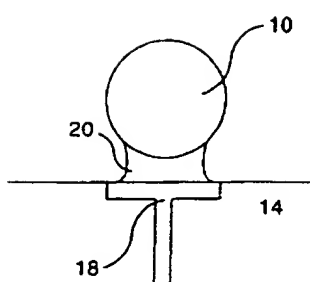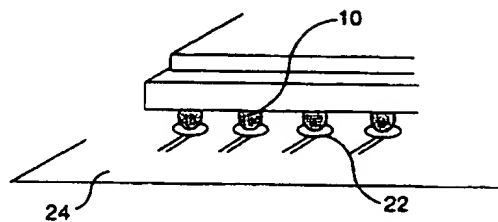12. The inspection machine according to claim 11 wherein said at least light source is composed of light emitting diodes (LED) in the form of a light ring.
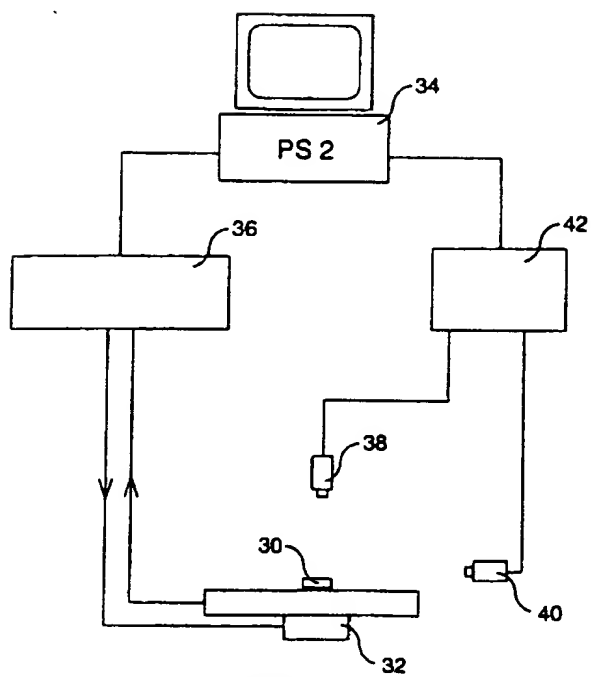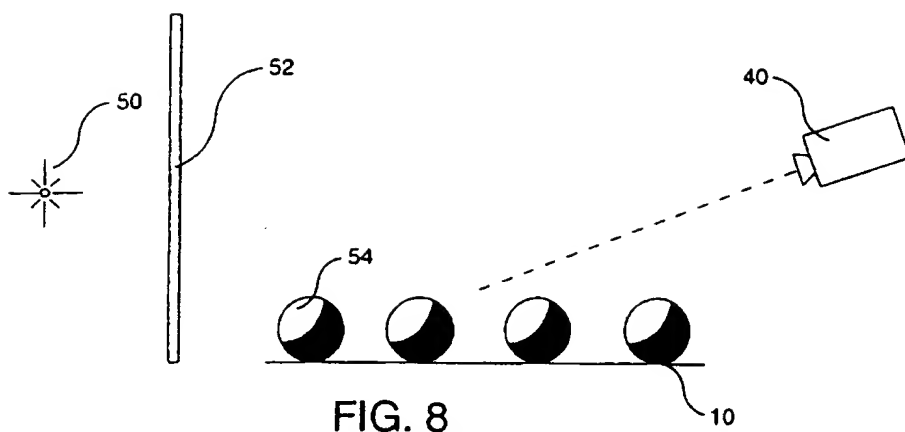
8
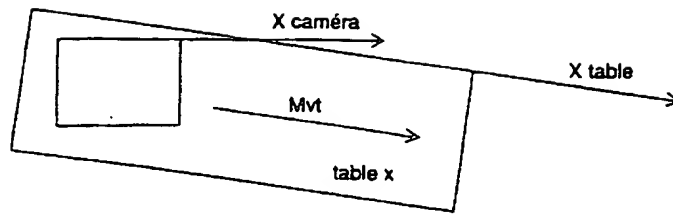
FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6

FIG. 7

FIG. 8

FIG. 9

FIG. 10

11

X caméra

X table

Mvt

table x

FIG. 11

DRIFT

FIG. 12

FIG. 13

Plan

Z

θ

X

Y

FIG. 14

60

30

FIG. 15

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
D,A	US-A-5 058 178 (RAY) * abstract * * column 1, paragraph 2 * * column 4, line 25 - line 42 * * column 4, line 52 - line 60 * * column 5, line 46 - line 59; figure 2 * ---	1,3,11, 12	G01N21/88 G01R31/308 //H05K13/08
A	EP-A-0 472 041 (HITACHI) * abstract * * column 4, line 39 - line 51 * * column 6, line 7 - line 48 * * column 7, line 5 - line 15 * * column 8, line 57 - column 9, line 1 * * column 9, line 14 - line 35 * * column 9, line 47 - line 58 * * column 10, line 17 - line 27 * * column 10, line 47 - line 51 * * figures 5,6,11,13 * ---	1,3-6,11	
A	US-A-4 296 474 (HURT) * abstract * ---	1,2	**TECHNICAL FIELDS SEARCHED** (Int.Cl.6) G01N G06F G01R
A	PROCEEDINGS 1987 IEEE INTERNATIONAL CONFERENCE ON ROBOTICS AND AUTOMATION, Raleigh, US, 31 March - 3 April 1987, pages 509 - 514 W.E. BLANZ ET AL. 'Image analysis methods for solder ball inspection in integrated circuit manufacturing' * abstract * * column 1, paragraph 1 * ---	1,11	
A	EP-A-0 471 196 (SIEMANS) * page 3, line 44 - line 57 * * page 4, line 13 - line 15 * --- -/--	1,11	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	18 January 1994	THOMAS, M

EPO FORM 1503 03.82 (P04C01)

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	RESEARCH DISCLOSURE January 1992 , HAVANT GB RD33317 'Solder ball connection (SBC) co-planarity with X-ray technology' -----		
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	18 January 1994	THOMAS, M